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14. ABSTRACT
Utilizing experienced gained from analysis of TODWL and P3DWL data, we have been analyzing the shipboard HRDL data taken during DYNAMO with a focus on occasions when rain is in the field of view. In particular, investigating if the HRDL data can be used to discriminate between the air motions and the hydrometeor motions occurring simultaneously within the illuminated volumes. A second main objective of the past years' research was to use the HRDL data and the W band radar data taken aboard the USS Revelle to investigate vertical motions within physically thick (optically thin) cirrus layers.

Much of the first year's effort has been in acquiring HRDL data, W-band radar data, shipboard flux measurements and observer notes for cases studies with and without rain. This has been followed by a total reprocessing of the raw HRDL data in order to understand what can be obtained from it regarding our main objectives.

The HRDL data is recorded using auto-correlations of 6 lags. A main conclusion from our analyses and reprocessing were that, 6 lags are insufficient to allow us to discriminate rain from air motions under most conditions. In addition, we also found that using just 10 data points from the HRDL data to obtain 30 meters of range resolution risks a high bias in the LOS wind estimation.

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Investigation of the Air-Wave-Sea Interaction Modes Using an Airborne Doppler Wind Lidar:

Analyses of the HRDL data taken during DYNAMO

Annual Progress Report
Under
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Background

One of the main objectives of our research was to see if what was learned from the TODWL (CIRPAS) and P3DWL (NRL) experience regarding "rain in the field of view" of Doppler Wind Lidar (DWL) data could be applied to the shipboard HRDL (High Resolution Doppler Lidar) observations taken during DYNAMO. A second objective was to use the HRDL data and the W band radar data taken aboard the USS Revelle to investigate vertical motions within physically thick (optically thin) cirrus layers. During our evaluation of the HRDL data we have added a third objective which is to investigate dry convection rolls (Organized Large Eddies, OLE) from the perspective of a ship-borne DWL for comparison with that obtained from an airborne DWL during TODWL flights in April 2007 near Monterey, CA. This additional research objective is tightly associated with the research we are doing under another ONR DRI, the Unified Physical Parameterization for Extended Forecasts DRI, where the EDMF flux parameterization is being evaluated for its use in numerical models for seasonal predictions.

Selecting times for initial analyses

We used the following reports and data products/images available from the DYNAMO field catalogue and the NOAA ESRL ftp data site to classify the days during the period of October 1, 2011 – December 5, 2011:

- TOGA operations summaries
- DYNAMO weather discussion reports
- Revelle science/operations summaries
- Revelle shipboard rain measurements
- Revelle NOAA vertically pointing W-band radar image products
- Revelle TOGA scanning C-band radar image products

Utilizing these reports and data products, we classified the days into five categories where most of the day was: 1) Mainly clear (no rain); 2) Rain; 3) Mix (clouds, sun, some convection); 4) wind speeds greater than 5 m/s at 10 meters and no clouds; and 5) wind speeds greater than 5m/s at 10 meters when cloud streets are reported or seen in the cloud imagery.

The following days were selected for each category and we have obtained the NOAA HSRL lidar data for an example of each data case (in bold) to be used in further analysis:

- Mainly clear – 10/05, 10/06, 10/08,10/09, 10/20, 11/13 and **12/01**
- Rain – 11/24, **11/25,** 11/28, 11/29
- Mix – 10/10, 10/11, 10/18, **11/20**
- Rolls but no clouds - **TBD**
- Rolls with cloud streets – **TBD**

Underlying question

Can the HRDL data be used to discriminate between the air motions and the hydrometeor motions occurring simultaneously within the illuminated volumes?

The HRDL data is recorded using auto-correlations of 6 lags. Post processing then performs an FFT on the time series of the lags to produce LOS velocity estimates. This HRDL data recording system is of the "legacy" category. As mentioned above, rather than recording the raw digitized signal from the detector at 100 MHz or 500 MHz as is done with today's DWLs, the HRDL system records the auto-covariance values of six lags (performed with hardware rather than software). The velocity resolution is thus, limited and thus, we do not expect to resolve air and hydrometeor speeds closer than several m/s.

Using TODWL data to evaluate HRDL's Auto-Correlation Function (ACF)

Much of the first year's effort has been in acquiring HRDL data, W-band radar data, shipboard flux measurements and observer notes. This has been followed by reprocessing the raw HRDL data to understand what can be obtained from it regarding our first objective (discriminating rain from air motion).

Since we cannot reverse process the HRDL line-of-sight products to get back to the raw digitized frequency data, we chose to use some of the TODWL data (pointing down from 3 km) to simulate the HRDL data recording and subsequent processing. In the reprocessing of the TODWL data we use the following inputs:

- Number of lags to perform in each gate's data points.
- Size of the FFT window (with zero-padding beyond gate length).
- Gate length (digitized points).
- Digitization rate.
- Shots to investigate.
- Range gates to investigate.

Our processing attempts to replicate that used by NOAA is done to establish a baseline for any added value we may provide. The processing proceeds as follows:

1. Load the 'signal' file for each shot to be investigated.
2. For each requested shot isolate the data for all range gates.
3. Using Matlab's 'xcorr' function determine the ACF for each gate using the predefined number of lags.
4. Apply an FFT to each of the range gates for both the ACF and the Raw signal data.

In the application of an FFT to the TODWL lag data we use several schemes. Since non-accumulated spectra of aerosol features often produce weaker signals, the ground return was used as a surrogate aerosol signal.

Three different sets of parameters were tested:

1. using a gate range of 10 digitized points, 6 lags and a 128 FFT window (HRDL).
2. using a gate range of 64 digitized points, 64 lags and a 256 FFT window (TODWL).
3. using a gate range of 64 digitized points, 40 lags (similar ratio to HRDL 6 lags/10 points) and a 256 FFT window.

Some examples of comparisons made between these products are shown here with explanation in the figure caption.

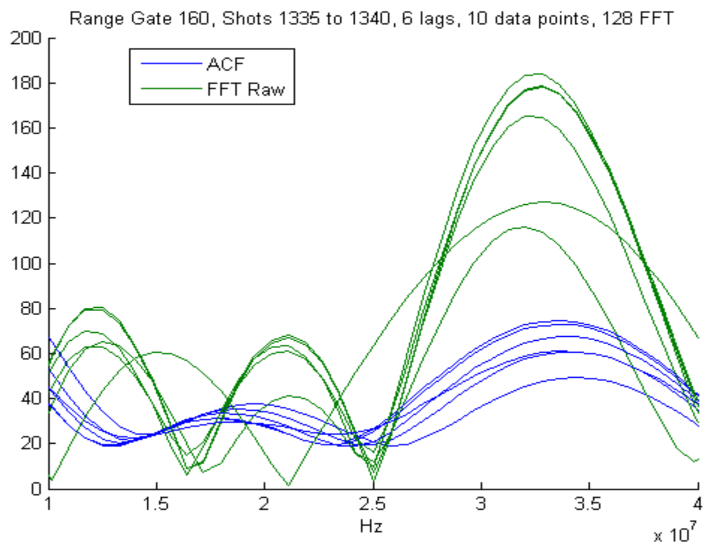

Figure 1. HRDL scheme used on TODWL data for comparison between ACF and raw data FFT'S of consecutive shots at same gate range. This is a comparison of consecutive shots, consisting of 10 data points, at and near the ground between the ACF and raw signal. Both examples were processed using an FFT zero padded to 128 points.

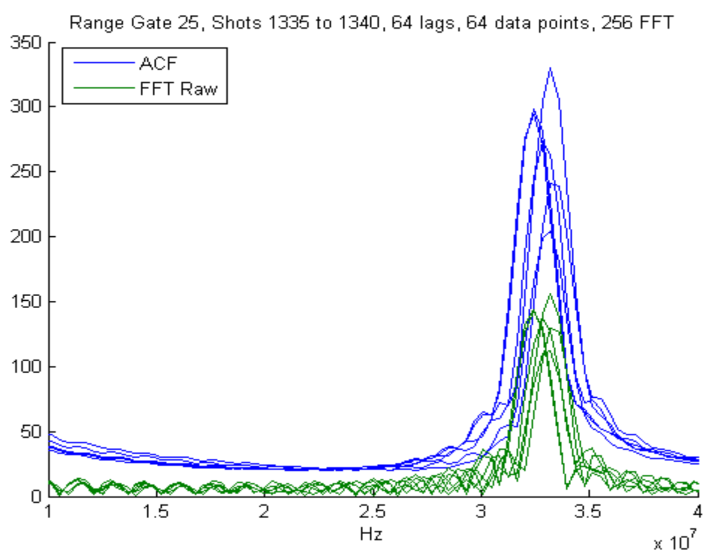

Figure 2. TODWL scheme comparison between ACF and raw data FFT's of consecutive shots at same gate range. This is a comparison of consecutive shots, consisting of 64 data points, at and near the ground between the ACF and raw signal. Both examples were processed using an FFT zero padded to 256 points.

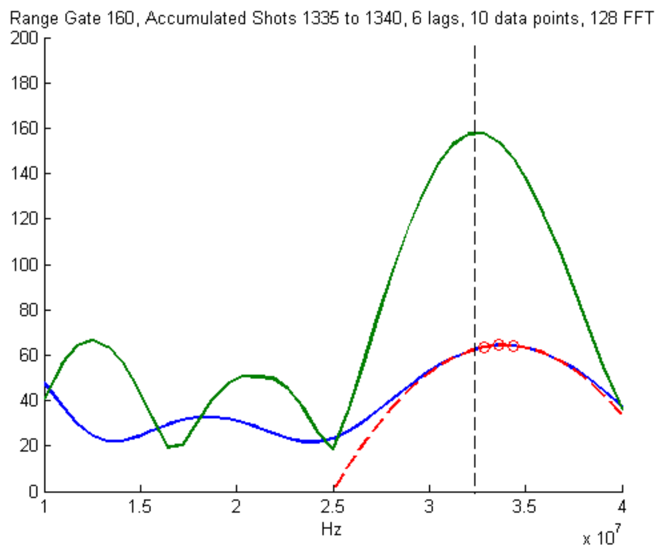

Figure 3. HRDL 10 data point scheme used on TODWL data for comparison between ACF and raw data FFT on accumulated shots at same gate range. This is a comparison of the accumulated shots (from Fig. 1) at and near the ground of the ACF and raw signal FFT's. Using the HRDL scheme a quadratic is applied to the 3 'top' points of the ACF FFT.

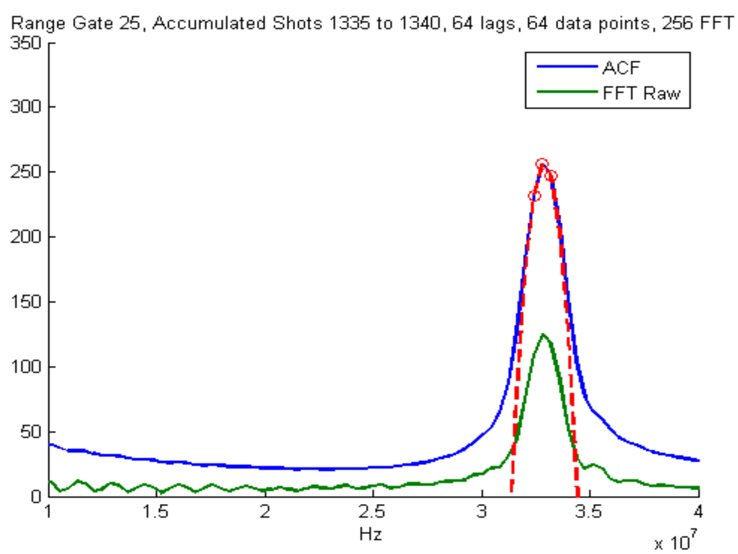

Figure 4. TODWL scheme comparison between ACF and raw data FFT of consecutive shots at same gate range. This is a comparison of the accumulated shots (from Fig. 2) at and near the ground of the ACF and raw signals FFT's. Using the HRDL scheme a quadratic is applied to the 3 'top' points of the ACF FFT.

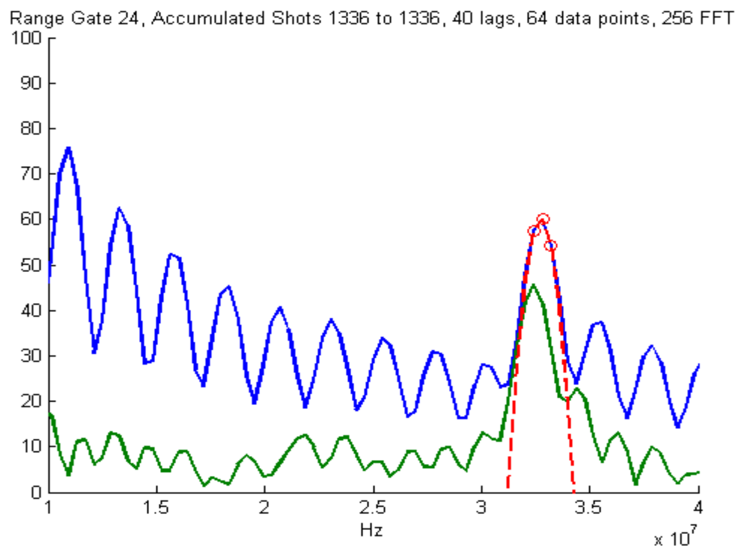

Figure 5. TOWDL scheme with similar lag ratio to DYNAMO and for a gate above ground. This is a comparison of a single shot at the gate, just above the ground between the ACF using 40 lags in a 64 data point set and the raw signal FFT's. Using 40 lags is a similar ratio to HRDL's method of using 6 lags in 10 data points. In the range gate directly above the ground it can be expected to observe two spectral features, one from the solid ground return and one from the diffuse aerosols. We cannot resolve two spectral features using the HRDL scheme.

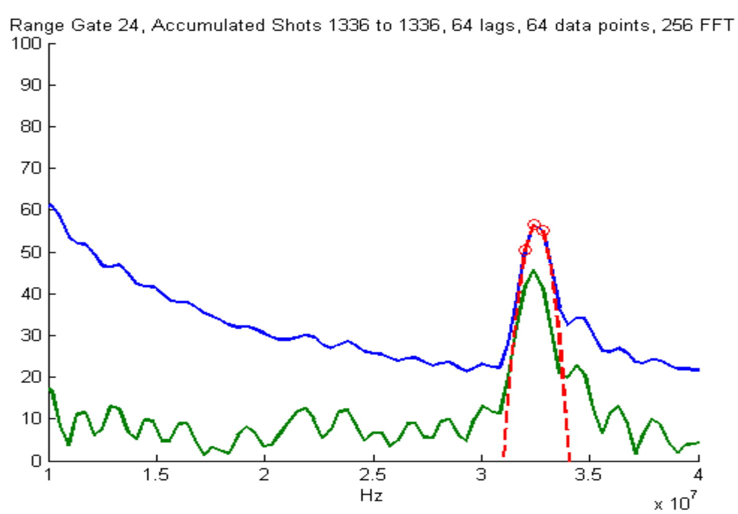

Figure 6. TODWL scheme comparison with 64 lags for a gate above ground. This is a comparison of a single shot at the gate just above the ground between the ACF using all 64 lags in a 64 data point set and the raw signal FFT's. In the range gate directly above the ground it can be expected to observe two spectral features, one from the solid ground return and one from the diffuse aerosols. A secondary spectral feature can now be identified in both spectra.

Our conclusions (in some cases stating the well known), from the analyses reported through Figures 1 – 6 are:

1. 6 lags are insufficient to allow us to discriminate rain from air motions where:
   DeltaLOS < 10 -15 m/s
   Where DeltaLOS = abs(Sqrt(U^2+V^2)*sin(phi) – DropFV)
   1. U & V are the horizontal components of the wind
   2. Phi is the half cone angle
   3. DropFV is the median fall velocity of the hydrometeors

2. Using just 10 data points from the HRDL data to obtain 30 meters of range resolution risks a high bias in the LOS wind estimation. (Figure 3.)

Future Research Plans

Over the next 12 months, we plan to work up case studies using radar, HRDL and boom fluxes to answer the following questions:

1. Are there DYNAMO cases when we are able to discriminate between hydrometeor and air motions?
2. Can we see waves in the cirrus layers with both the W-Band and HRDL instruments?
3. Are we able to document the proportioning of Eddy Diffusivity and Mass Flux terms (in the EDMF unified physical parameterization) throughout the circulations associated with OLEs?

We plan to use sensible and latent heat flux time series derived from the Revelle flux booms. An example of such a time series in shown in Figure 7. We are particularly interested in the periodic sensible heat flux features such as those seen between 279.8 and 280. Coherent structures in the latent heat flux between 279.6 and 279.8 are also targets for examining what is being seen with the HRDL during these time periods.

In addition to the flux data we will overlay the HRDL data, both SNR (Figure 10) and LOS velocity (Figure 9) data to prospect for correlations between HRDL resolved velocity/SNR structures (e.g. rolls) and the fluxes . The W band radar velocities and signal strengths (Figure 8) will also be used to explore the MBL and lower troposphere for organized structures where clouds are a part of the signature.

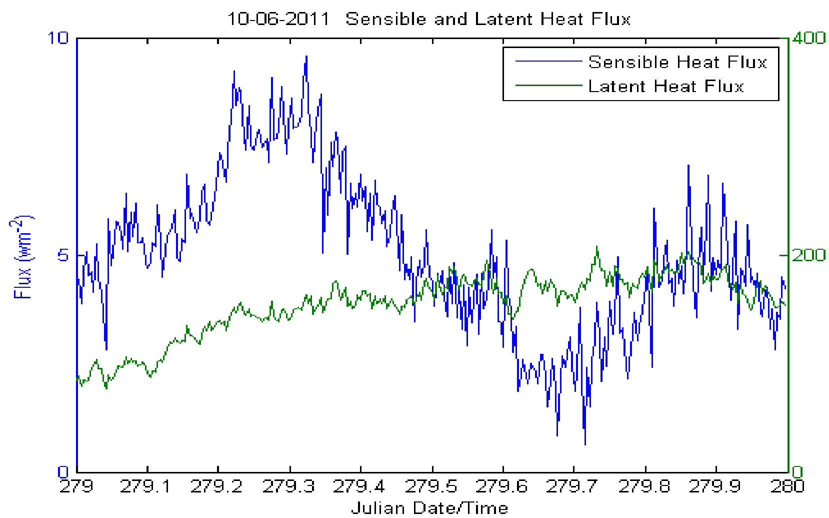

Figure 7. A sample time series of latent and sensible heat fluxes derived from the Revelle ship boom data.

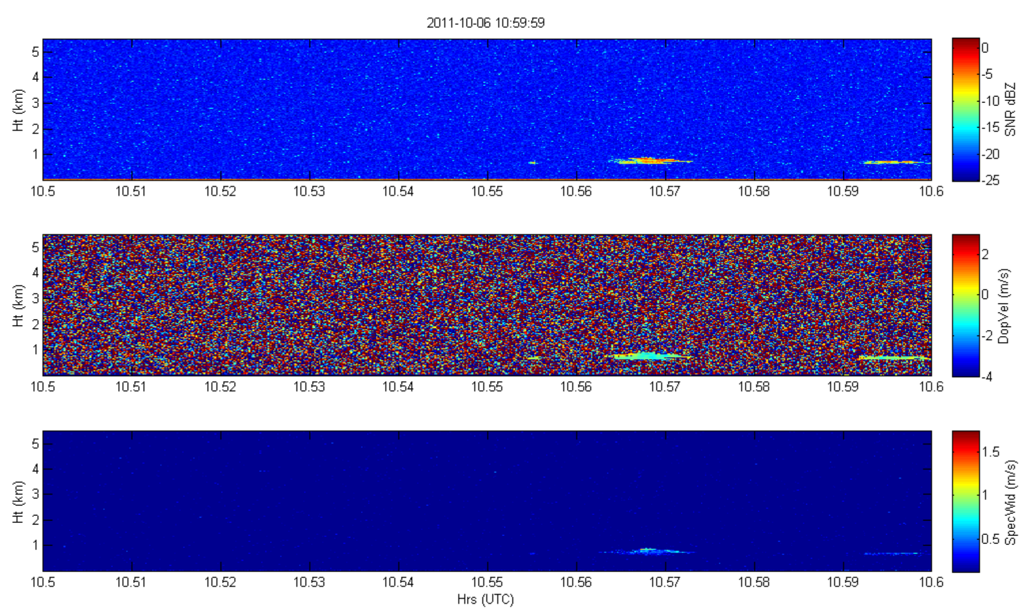

Figure 8. Example of the vertically pointed W band radar during clean air conditions.

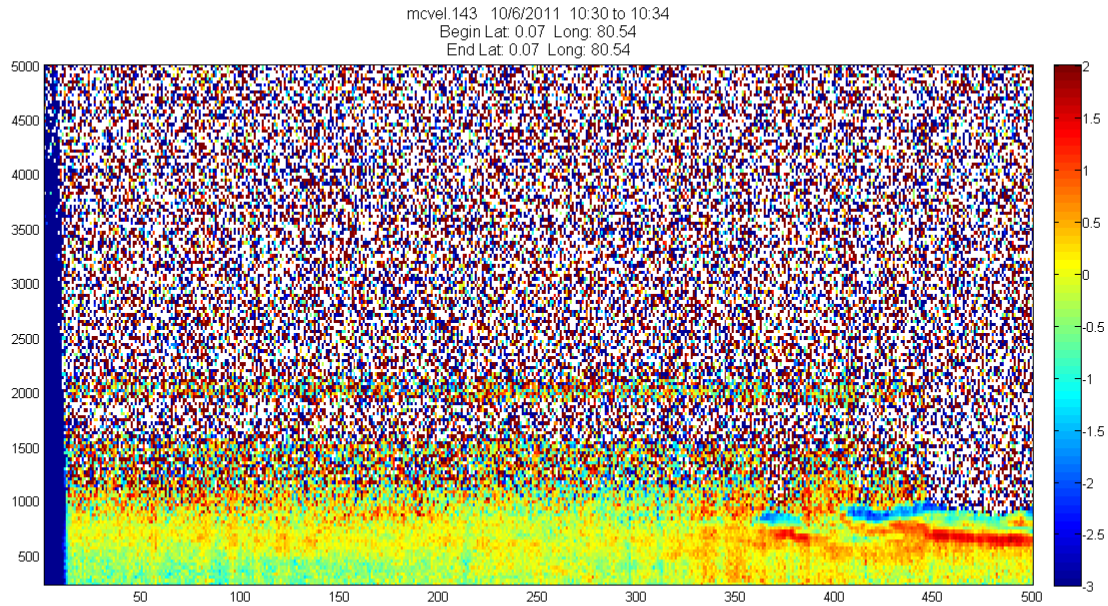

Figure 9. Example of the vertical air speeds from the vertically pointed HRDL

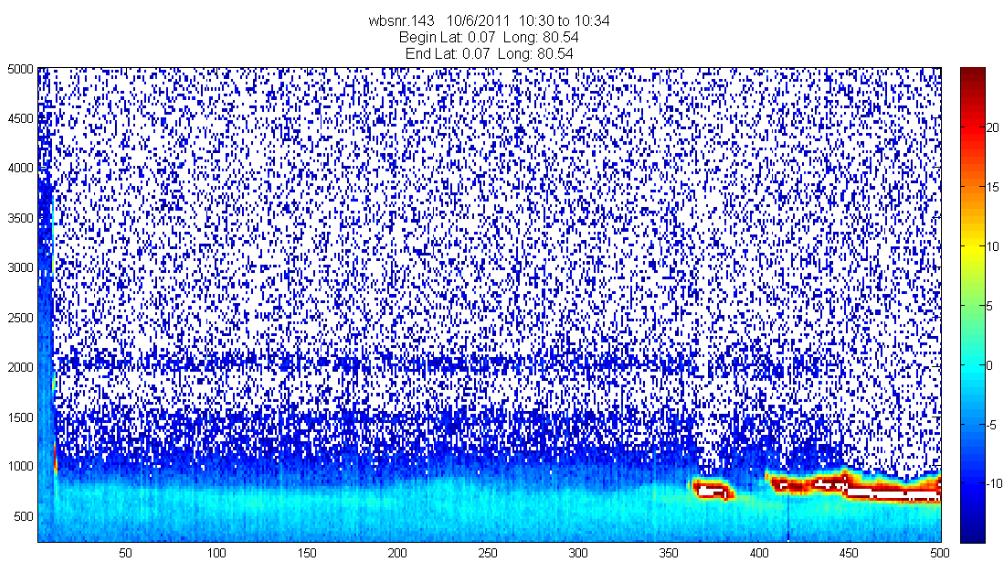

Figure 10. The wide band SNR for the vertically pointed HRDL for the same time period as that in Figure 9.

Summary

We have acquired raw HRDL data and have been able to reprocess it to determine the velocity precision achievable from an ACF-based upon 6 lags. In order to better understand the differences between the TODWL data (with which we have more than 10 years experience) and the HRDL data, we used some TODWL LOS observations digitized at 100 MHz to simulate HRDL recording of 6 lags with subsequent FTT processing. Our current position is that it is highly unlikely that we will be able to discriminate between vertical air motions and that of hydrometers within the same HRDL illuminated volume. It is possible, however, that we will be able to flag those observations where the signal is being contaminated by precipitation.

We have begun to identify case studies for our studies of cirrus waves and organized rolls in the marine boundary layer. In the case of the cirrus, we are trying to tie the presence and amplitude of cirrus waves to prior or subsequent convective activity during DYNAMO. In the case of the organized (or semi-organized) boundary layer rolls, we are investigating if the flux measurements near the surface are coupled with the cycle of increased and decreased 10 meter winds as the rolls are advected past the Revelle.

Access to the critical data sets has been established and we expect to accelerate our analyses during the second year of effort.